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STATIC-THRUST TESTS OF SIX ROTOR-BLADE DESIGNS ON A HELICOPTER IN THE LANGLEY FULL-SCALE TUNNEL

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WASHINGTON

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ADVANCE RESTRICTED REPORT

STATIC-THRUST TESTS OF SIX ROTOR-BLADE DESIGNS ON A HELICOPTER IN THE LANGLEY FULL-SCALE TUNNEL

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SUMMARY

Measurements of the static-thrust performance of six sets of rotor blades mounted on a helicopter fuselage have been made in the Langley full-scale tunnel. The rotor blades differ in surface condition, pitch distribution, airfoil section, plan form, and solidity. These differences are largely unsystematic. The variation of rotor thrust coefficient with torque coefficient and the power required to hover are compared for each set of blades. Because of the indeterminate condition of ground restraint caused by the wind-tunnel balance house and test-chamber walls, the absolute magnitude of the data is questionable but the comparative results are believed to be reliable.

A rotor of conventional construction having a doped fabric surface and relatively wide rib spacing required the most power to hover. The best hovering performance was given by two sets of plywood-covered blades of relatively low solidity, which required only slightly less power than a smoother and more rigidly constructed version of the conventional blades. The results indicate that the rotor-blade surface condition has a very important effect upon performance and that the optimum performance of any rotor design will be obtained only if the blades have a smooth and accurately contoured surface that will not deform during flight. The results further indicate that significant reductions in power can be obtained for this aircraft by the use of lower rotor speeds.

INTRODUCTION

Tests to determine the performance characteristics of a helicopter over a range of airspeeds were conducted in the Langley full-scale tunnel. This report presents measurements of the static-thrust performance of six sets of rotor blades supplied by the Air Technical Service Command, Wright Field. These sets of blades differ in

APPARATUS

The helicopter was mounted at the three landing-gear supports on a six-component strain-gage balance. A photograph of the test setup is shown as figure 1. The center-of-gravity location for the tests was chosen as the point on the center line of the rotor shaft 56.52 inches below the plane of the flapping hinges. This location was based on information supplied by the manufacturer and falls within the center-of-gravity range that corresponds to normal gross weight.

A strain-gage-type torque meter mounted on the main rotor shaft measured the torque input to the rotor. The total-pitch angle was measured by an indicator attached to the control linkage and was calibrated against a protractor mounted on a rotor blade at the 14.25-foot radius. The indicators for the blade pitch angle, strain-gage balance, and torque meter, together with the remote-control system that operated the engine and flight controls of the helicopter, were located in a test house at the rear of the balance house. (See fig. 1.)

Observations of the surface roughness of the six sets of rotor blades were made with a 40-power microscope. A prism attachment permitted measurement of the height of the roughness particles.

ROTOR BLADES

The geometric characteristics of each of the rotor blades are presented in table I and figure 2, and photographs of the blades are shown as figure 3.

Description of Rotor Blades

The blades of rotor A, which are the production blades of the helicopter tested, have a radius of 19 feet measured from the center of rotation. The blades are tapered in plan form, have a total area (three blades) of 65.4 square feet, are untwisted, and have an NACA 0012 airfoil section. Each blade consists of a tubular steel spar to which 36 wooden ribs are attached. The rib spacing is approximately 6 inches at the blade root

Rotor-Blade Surface Roughness

After the static-thrust tests had been completed, the surface roughness of each rotor was determined. The amplitude and frequency of the rotor-blade surface waves were measured at the 80-percent radius on the upper and lower surfaces approximately $1\frac{1}{2}$ inches from the leading and the trailing edges of each rotor blade. The surface roughness of rotors A, B, C, and D is primarily due to the fabric weave. The pigmented-dope finish partly filled the small depressions and left a wavy surface. The amplitude of the waves is approximately 0.0011 inch and the spanwise and chordwise frequency on both the upper and lower blade surfaces ranges from 79 to 106 waves per inch. The contoured forward portion on the blades of rotors B and D is aerodynamically smooth. It was not possible to measure the surface roughness of rotors E and F with the microscope used, although these two rotors have definite contour defects. Between the leading-edge strip and the plywood covering on both rotors E and F there was a U-shaped furrow approximately 1/64 to 1/32 inch wide and deep. The furrows in the blades of rotor E were filled for all the tests, but those in the blades of rotor F were filled for the second series of measurements only. In spite of the application of filler to the most pronounced discontinuities, the blade contour differs noticeably from the true airfoil section because of flat spots and protuberances, the elimination of which would require a complete resurfacing of the blades.

TEST PROCEDURE

The static-thrust tests were made at a rotor-shaft tilt of 0° and with the longitudinal and lateral feathering controls locked in the neutral position. Data are presented for engine speeds ranging from 1600 to 2100 rpm (rotor speeds of 171 to 225 rpm) for indicated total-pitch angles from 4° to 12°. The helicopter was trimmed for zero yawing moment about the center of gravity throughout the tests by adjusting the pitch angle of the tail rotor. Static-thrust measurements were first taken for four sets of rotor blades and the tests were later repeated for all six rotors. The two rotors for which only one test was made are rotors C and E.

Power Required for Hovering

The main-rotor shaft power required for the helicopter to hover at sea level with each set of rotor blades has been estimated from figure 5 and is given in table II. The calculations are presented for rotor-thrust coefficients of 0.00387 and 0.00464, which correspond to a gross weight of 2500 pounds, a rotor-shaft tilt of 0°, and engine speeds of 2300 and 2100 rpm (rotor speeds of 246 and 225 rpm), respectively. The percentage less horsepower required for each set of blades, referred to rotor A, is also included.

The results indicate that rotor A requires approximately 148 and 140 horsepower for hovering at engine speeds of 2300 and 2100 rpm, respectively. The curves of figure 5 also predict that rotor C will permit the helicopter to hover with an average of 7 percent less power than rotor A and that more than 3 percent additional power would be saved if rotor B were installed. Rotor D would require an average of 4 percent less power than rotor A. Rotors E and F would need approximately 12 and 13 percent less power, respectively, to hover than rotor A.

The thrust in excess of 2500 pounds that the five experimental rotors would produce at engine speeds of 2300 and 2100 rpm for the same power input that the production blades (rotor A) require to hover (approximately 148 and 140 horsepower, respectively) is also included in table II. The greatest single gain is shown at 2300 rpm by the blades of rotor F; for a power input of approximately 148 horsepower, these blades produce almost 300 pounds more thrust than the blades of rotor A.

The advantage of operating rotors at lower rotational speeds and thus effecting a reduction in profile drag is clearly shown by the data in table II. Almost 8 horsepower would be saved in hovering with rotor A by operating at an engine speed of 2100 rpm instead of 2300 rpm (rotor speeds of 225 and 246 rpm, respectively). The power required for hovering with each rotor continues to decrease with increasing thrust coefficient for values of C_T as high as 0.00582 (an engine speed of 1875 rpm or a rotor speed of 201 rpm). At this thrust coefficient, which is the highest afforded by the data, rotors A and F require approximately 136 and 119 horsepower, respectively. (See fig. 5.)

1. The condition of the rotor-blade surface has a large effect upon the rotor performance. The optimum performance of any rotor design will be obtained only if the blades have a smooth and accurately contoured surface that will not deform during flight.

2. The production rotor, rotor A, requires more power to produce a given thrust throughout the range of total-pitch angle than any of the other blades tested. It is estimated that 148 and 140 horsepower are needed for these blades to hover at thrust coefficients of 0.00387 and 0.00464, respectively, which correspond to a gross weight of 2500 pounds and engine speeds of 2300 and 2100 rpm. The average saving in power required to hover at these thrust coefficients by rotors B, C, D, E, and F is approximately 10, 7, 4, 12, and 13 percent, respectively. For the same power input that rotor A requires to hover at an engine speed of 2300 rpm, rotor F will produce nearly 300 pounds more thrust.

3. The reduction in power required to hover that may be obtained by operating at lower rotor speeds is clearly shown for the blades tested. Savings of as much as 8 horsepower are obtained by hovering at an engine speed of 2100 rpm as compared to 2300 rpm (thrust coefficients of main rotor C_T, 0.00464 and 0.00387, respectively). The data indicate additional savings with further reduction in engine speed to values at least as low as 1875 rpm (C_T = 0.00582), which is the lowest engine speed afforded by the data when a gross weight of 2500 pounds is assumed.

4. Linear washout appears to result in increased efficiency at the higher thrust coefficients, as indicated by the relative performance of rotors E and F. The magnitude of this effect cannot be accurately estimated from these data, however, because of the limits of experimental accuracy and the surface differences between these rotors.

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TABLE II.- ESTIMATE OF MAIN-ROTOR SHAFT POWER REQUIRED FOR HELICOPTER TO HOVER AT SEA LEVEL WITH ROTORS TESTED

Rotor	Engine speed, rpm					
	2300			2100		
	$C_T = 0.00387$		Excess thrust for 147.7 hp (1)	$C_T = 0.00464$		Excess thrust for 140.0 hp (1)
	Horsepower required to hover	Percent less power required than for rotor A		Horsepower required to hover	Percent less power required than for rotor A	
A	147.7	------------	0	140.0	------------	0
B	131.1	11.2	233	126.9	9.4	182
C	137.4	7.0	155	130.8	6.6	128
D	140.8	4.7	97	134.8	3.7	74
E	127.6	13.6	278	124.7	10.9	215
F	128.2	13.2	298	123.4	11.9	258

[1]Thrust in excess of the assumed gross weight of 2500 lb which would be produced by each rotor for the same power input that rotor A requires to hover.

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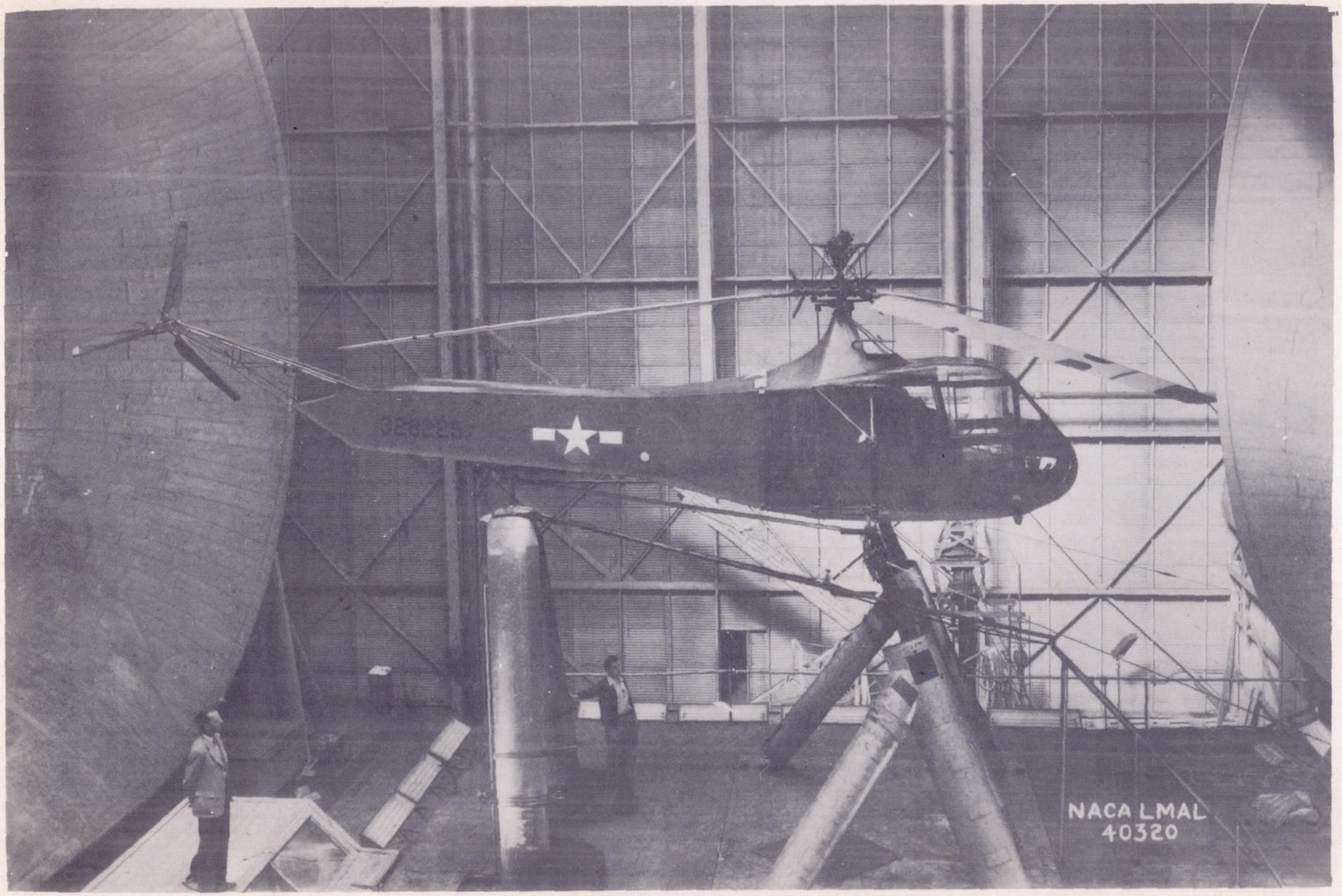

Figure 1.- Helicopter with production rotor (rotor A) mounted in Langley full-scale tunnel.

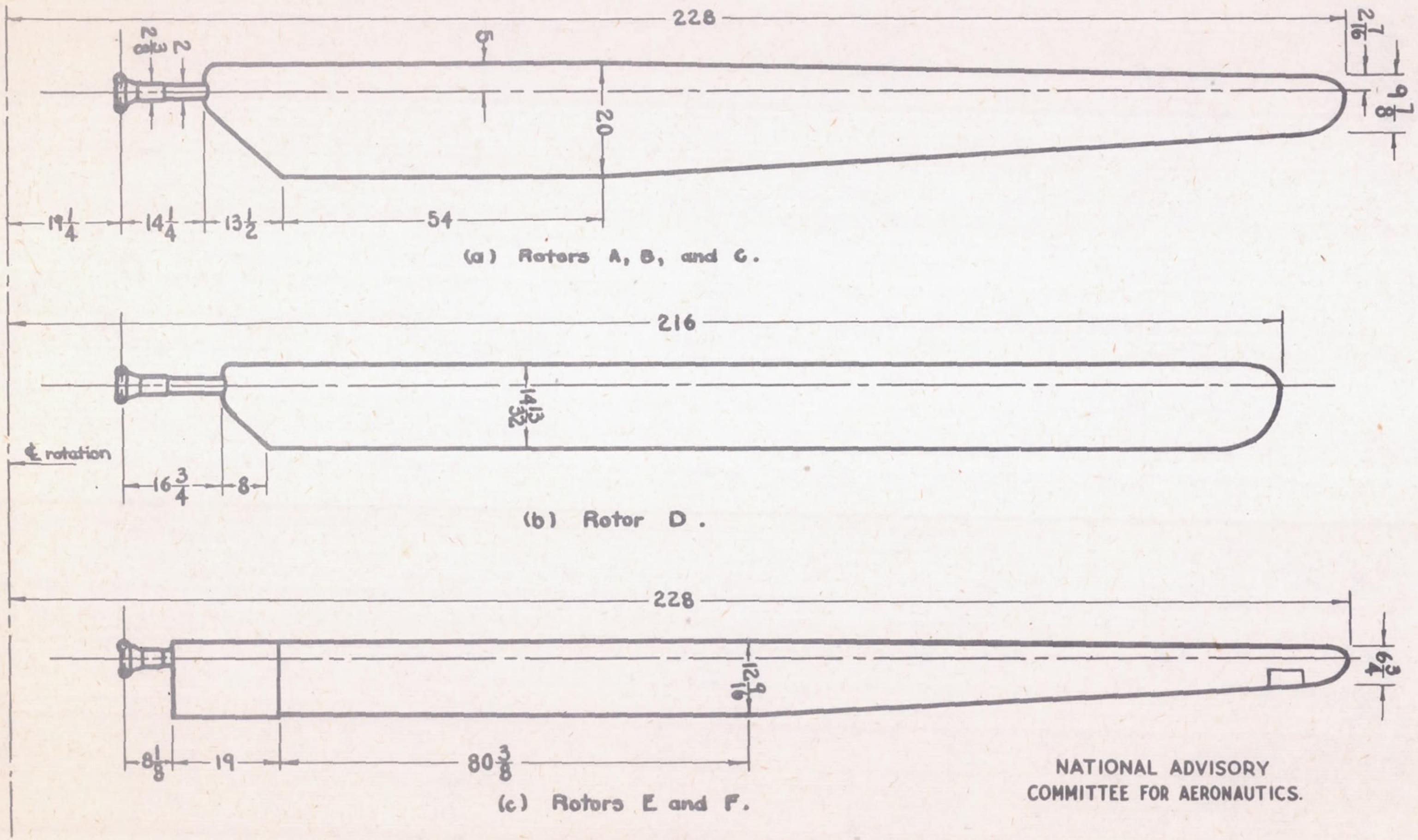

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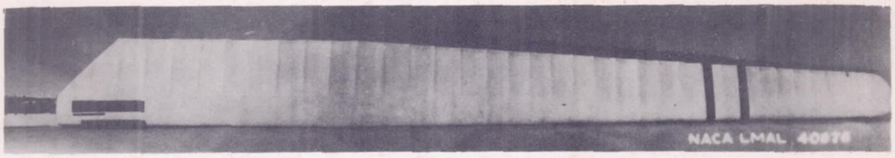
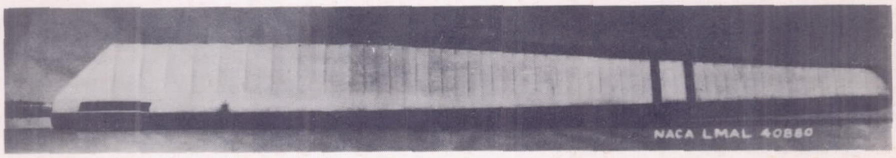
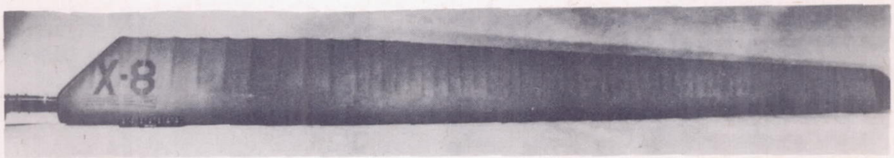
Figure 2. - Rotor blades tested in static thrust.
(All dimensions given in inches.)



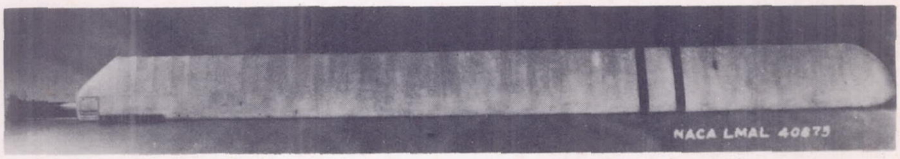
(a) Rotor A.



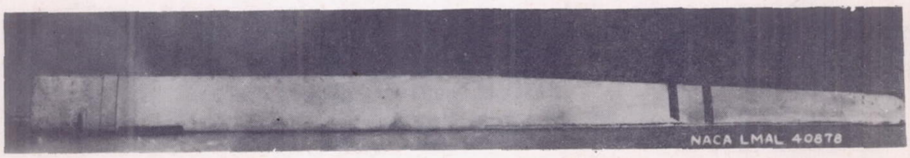
(b) Rotor B.



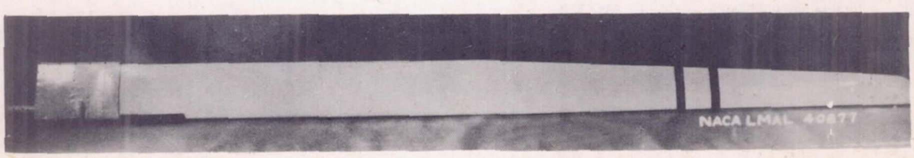
(c) Rotor C.



(d) Rotor D.

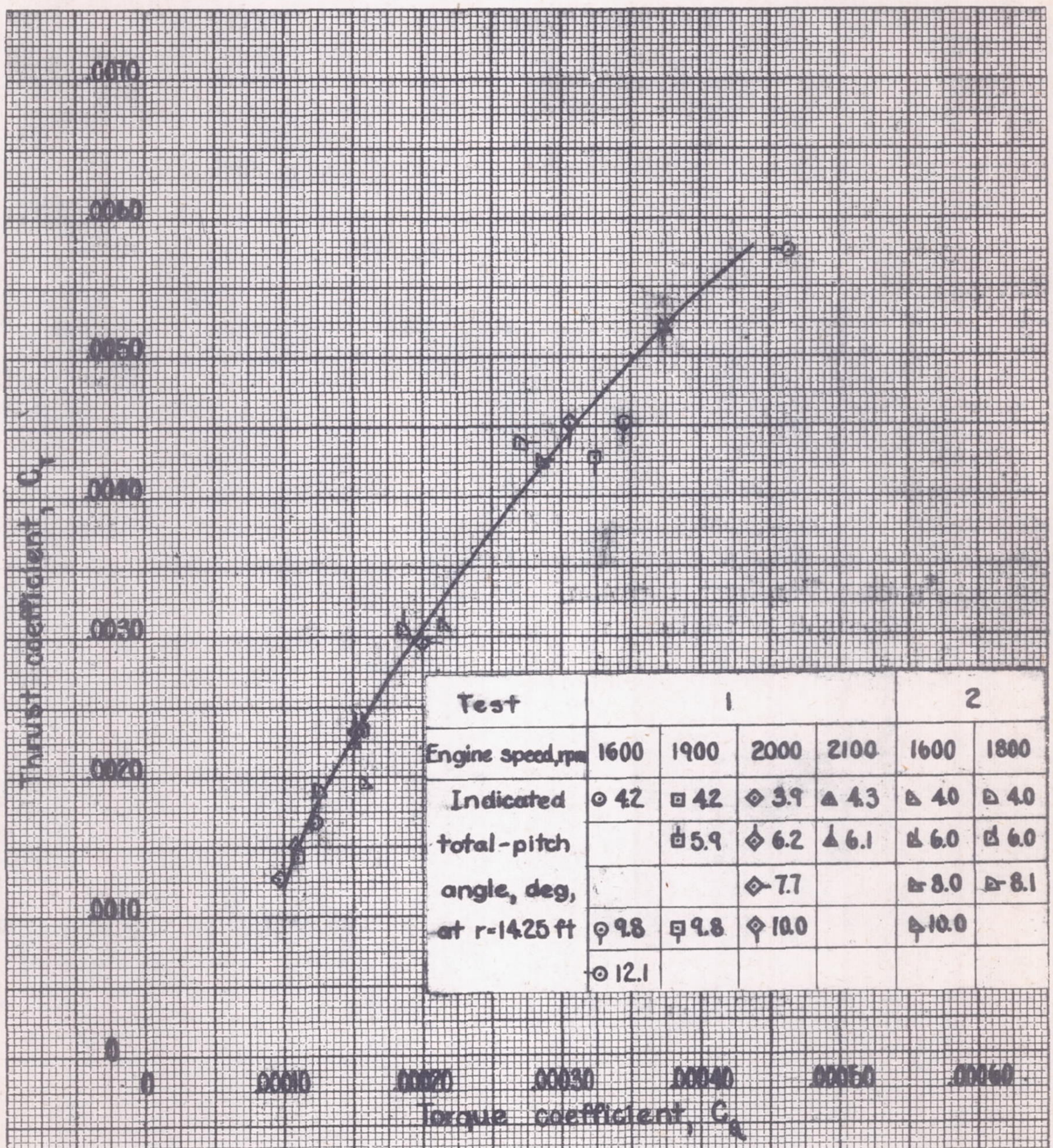


e) Rotor E.



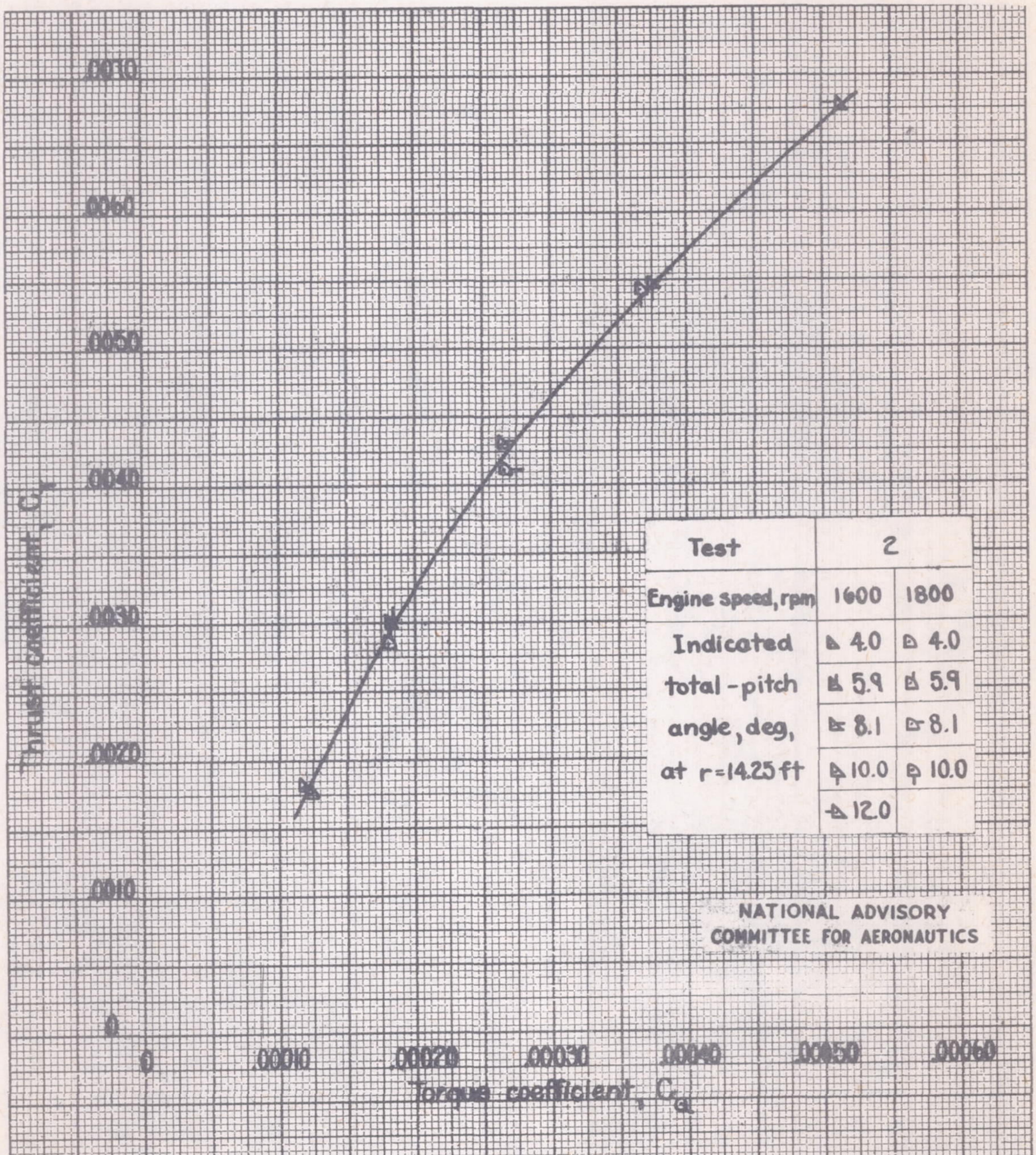
(f) Rotor F.

Figure 3.- Lower-surface views of a blade from each rotor tested on helicopter for static-thrust performance.



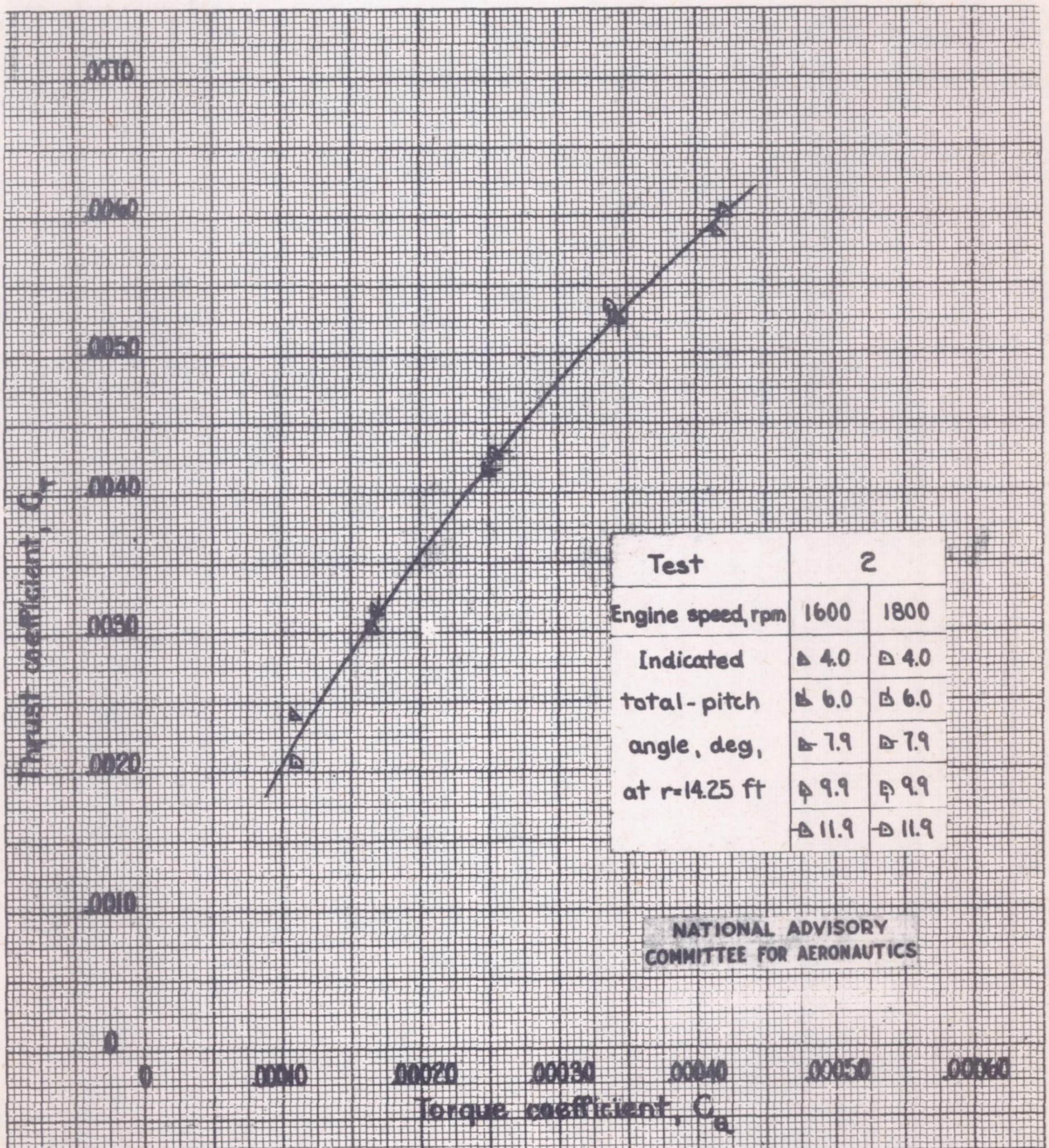
(a) Rotor A.

Figure 4. - Static-thrust performance of rotors tested.



(c) Rotor C.

Figure 4.- Continued.



(e) Rotor E.

Figure 4.- Continued.

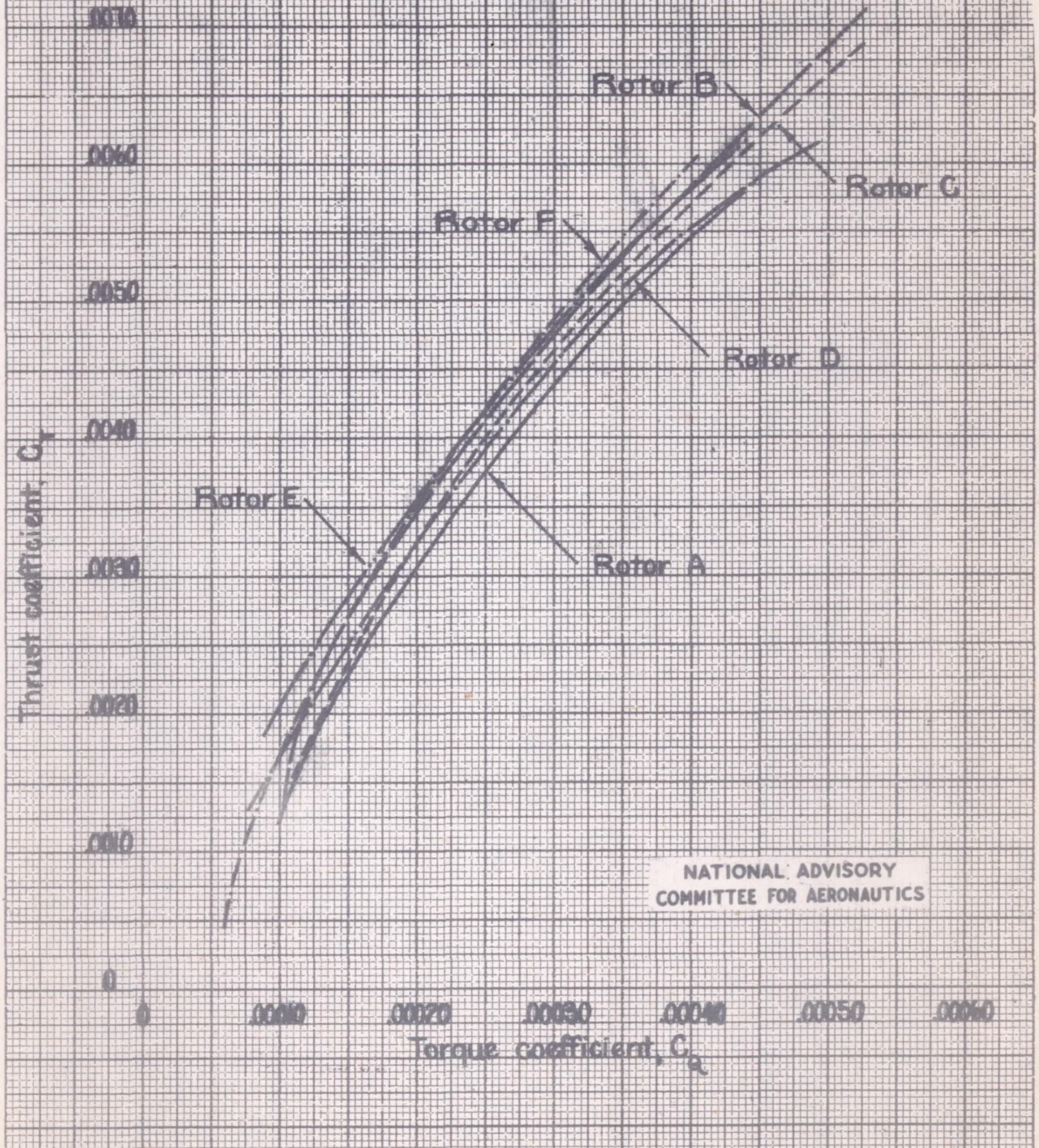


Figure 5.- Comparison of the static-thrust performance of the six rotors tested. (All coefficients are based on a 19-foot rotor-blade radius.)